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Enhancement of Thermal Conductivity of Cyanoacrylate with Different Types of Nanofillers and Loading

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Abstract

In this research, a method to enhance the thermal conductivity of cyanoacrylate is described. Multi-walled carbon nanotubes (MWCNTs) and graphene were used as nanofiller to fabricate high thermal conductivity of nanocomposites. It was determined that the additional of 0.4 vol% of MWCNTs and 0.5 vol% of graphene in cyanoacrylate has increased 204 % and 233 % of thermal conductivity of the nanocomposites, respectively. The improvement in thermal conductivity of nanocomposites is due to the uniform dispersion of nanofillers and strong interfacial bonding between graphene and MWCNTs, respectively with cyanoacrylate as confirmed by microscopy observations.

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Keywords: Ethyl cyanoacrylate; thermal conductivity; cyanoacrylate nanocomposite

1. Introduction

Photolithography and ion beam etching (IBE) has been widely used in the production of hard disk drive's recording head, called slider. Prior to photolithography and IBE process, three inch pallet (TIP) which is consist of

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slider bars, stainless steel window pane, glue, photoresist and stainless steel TIP base are assembled in encapsulation process. High thermal conductivity of TIP is required as the slider bars are heated by the bombardment of ions during the IBE process. Therefore, it is potential to create photoresist burn issues which can lead to masking defect resulting in yield loss. To solve this burn issue, heat transfer of the TIP was studied and expected to be improved by using superior heat transfer materials during assembly of the TIP. The existing poor thermal conductivity of cyanoacrylate greatly reduced the thermal conductivity in the TIP's assembly thereby reducing the heat dissipation. In order to achieve expected results, an improvement of heat transfer rate for the TIP assembly is to incorporate into the existing cyanoacrylate with higher thermal conductivity nanofiller is considered.

Polymer composite with alumina nitride, boron nitride, and alumina were used to enhance the performance of polymer[1]. However, about 30-60 vol% of fillers were required to achieve higher thermal conductivity values of 1-2W/mK[1]. In this research, multi-walled carbon nanotubes (MWCNTs) and graphene were used to fabricate high thermal conductivity of nanofiller cyanoacrylate composites. With low amount of nanofillers, graphene and MWCNTs based polymer nanocomposites we successfully demonstrated a highly efficient thermal conductivity cyanoacrylate due to the nanofillers having several excellent properties such as unique nanostructures, high aspect ratio[1–3], superior thermal conductivity up to 3000 W/mK at room temperature[4,5] and other desired qualities. In this research, graphene and MWCNTs were used as nanofiller to produce nanocomposites. Thermal conductivity of all samples were measured using Hot Disk TPS-2500S thermal constants analyzer. The effect of nanofillers on the morphologies and thermal conductivities of the nanofilled cyanoacrylate composite were studied.

Nomenclature

IBE	ion beam etching
TIP	three inch pallet
MWCNTs	multi-walled carbon nanotubes
vol %	volume percentage

2. Material and methods

2.1. Materials

In this research, cyanoacrylate was used as matrix for polymer composites. The cyanoacrylate, is formulated by ethyl cyanoacrylate with photoinitiator. MWCNTs and graphene were selected as nanofillers for polymer composites. MWCNTs with average 10-40 nm diameter and 1-25 μm length were purchased from Fibermax Composites. The purity of MWCNTs as received was 93 %. Graphene with average particle diameter of 15 μm and thickness of 11-15 nm were purchased from Skyspring Nanomaterials. The purity of graphene as received was 99.5 %.

2.2. Sample preparation

The MWCNTs and graphene were dried in an oven for one hour at 100 °C to remove moisture (Fig. 1.a). The method of preparation of graphene/cyanoacrylate and MWCNTs/cyanoacrylate nanocomposites are slightly different. The difference is acetone was needed to suspend MWCNTs before adding into the cyanoacrylate (Fig. 1.c). The acetone was used as solvent to disperse MWCNTs in an ultrasonic bath for 15 minutes with power of 108 W and resonance frequency of 68 kHz (Fig. 1.d). The acetone was removed by drying inside an oven at 70 °C (Fig. 1.e). The required weight of cyanoacrylate was weighed using an electronic scale (Fig. 1.b) and added with the as-dispersed MWCNTs (Fig. 1.f). For graphene/cyanoacrylate sample preparation, suspend graphene in acetone were not required before adding graphene into the cyanoacrylate. Hence, steps c, d, and e which are shown in Fig. 1. were skipped and direct mixing graphene with cyanoacrylate was conducted (Fig. 1.f).

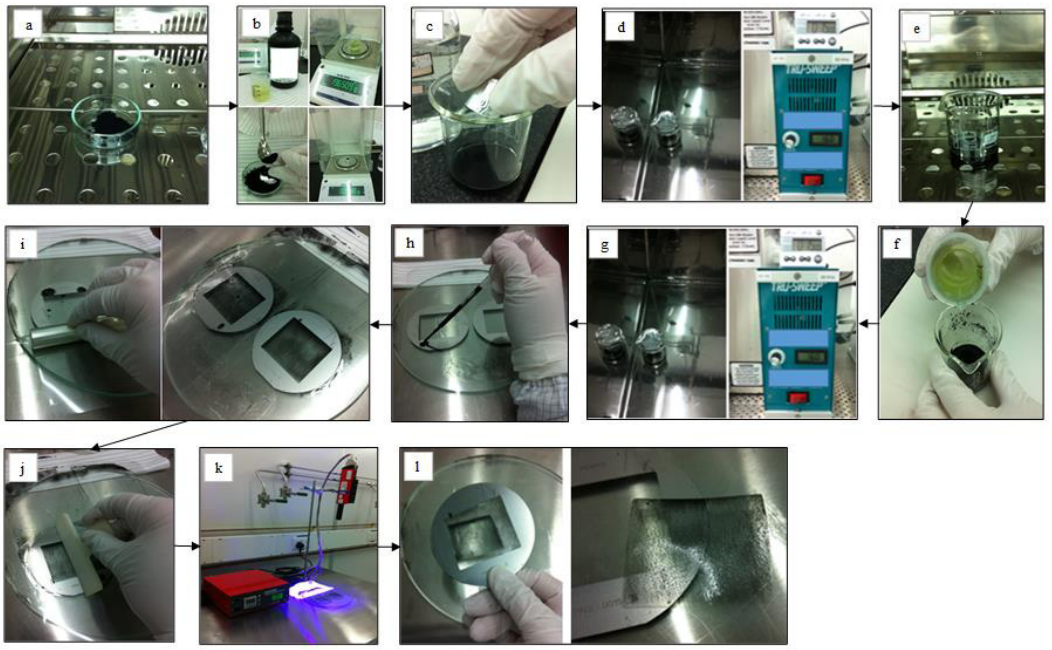

Fig. 1. Process flow of sample preparation.

Then, the mixtures of MWCNTs/cyanoacrylate and graphene/cyanoacrylate were sonicated for 30 minutes with power of 108 W and resonance frequency of 68 kHz (Fig. 1.g), respectively. To fabricate nanocomposite samples, the mixture was dispensed onto the area of the window pane which is placed on the 8 inch glass having the mylar plastic cover (Fig. 1.i). A mylar roller was used to push the mixture into the cavity of window pane (Fig. 1.i). After this, the surface of the mixture in the cavity of window pane was flatted using a glue spreader (Fig. 1.j). The mixture which is underneath the mylar plastic was cured using a UV light source for 180 seconds (Fig. 1.k). The cured sample was detached from glass plate and window pane (Fig. 1.l).

2.3. Characterization method

The morphologies of MWCNTs and graphene were characterized using Field Emission Scanning Electron Microscope (FESEM) (model: Hitachi SU8010). Cyanoacrylate nanocomposite samples were further observed and analyzed under Olympus BX50 microscope. The thermal conductivities of the prepared samples (width: 45 mm, length: 40 mm, thickness: 0.168 mm) were measured using a hot disk thermal constants analyzer (model: TPS2500S) at room temperature. Hot Disk using transient plane source method, ISO 22007-2:2008 which has been proven to be a highly effective and accurate method to measure the thermal conductivity of various materials.

3. Results and discussion

3.1. Morphology of the nanofiller

The morphology of fillers samples were characterized by FESEM as shown in Fig. 2. Fig. 2. (a) shows that the diameter of MWCNTs were at average of 10-40 nm. Agglomerations of MWCNTs into large bundles due to the van der Waal force exists between nanotubes can be observed in Fig. 2. (a). In addition, the agglomeration inhibited the

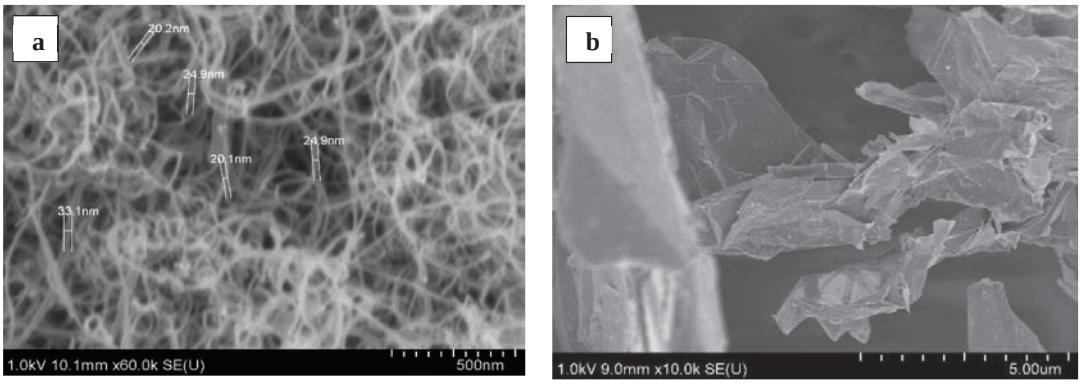

Fig. 2. SEM images of fillers materials. (a) MWCNTs under magnification of 60kX; (b) graphene under magnification of 10kX.

direct mixing of cyanoacrylate and MWCNTs. Thus, the dispersion of MWCNTs using acetone is important. Graphene sheets that were used as nanofiller are shown in Fig. 2.b. The graphene sheets are stacked in few layers due to the van der Waal forces. Therefore, graphene sheets are less agglomerated as compared to MWCNTs.

3.2. Morphology of the MWCNTs/ cyanoacrylate and graphene/ cyanoacrylate nanocomposite

Olympus BX50 microscope was used to investigate the surface morphology of samples. All the images were captured at 300 X magnification as shown in Fig. 3. and 4. The black area is the MWCNTs and graphene, respectively and the grey area is the cyanoacrylate matrix. The homogenous distribution and dispersion of MWCNTs and graphene within cyanoacrylate matrix was observed. From 0.1 to 0.5 vol%, the density of black area was increased because of more MWCNTs and graphene. It is seen that the addition of MWCNTs at 0.5 vol% and above caused the cured samples to have a curved surface and an unacceptable amount of trapped bubbles (Fig. 5.a). The same problems happened to the graphene/cyanoacrylate samples as well when 1 and 2 vol% of graphene was added (Fig. 5.b-c). In addition, a rough surface of the 2 vol% sample was observed due to the large cluster of graphene accumulation (Fig. 4.g). This indicates that the sample was overdosed with nanofillers and they are not suitable for the targeted application.

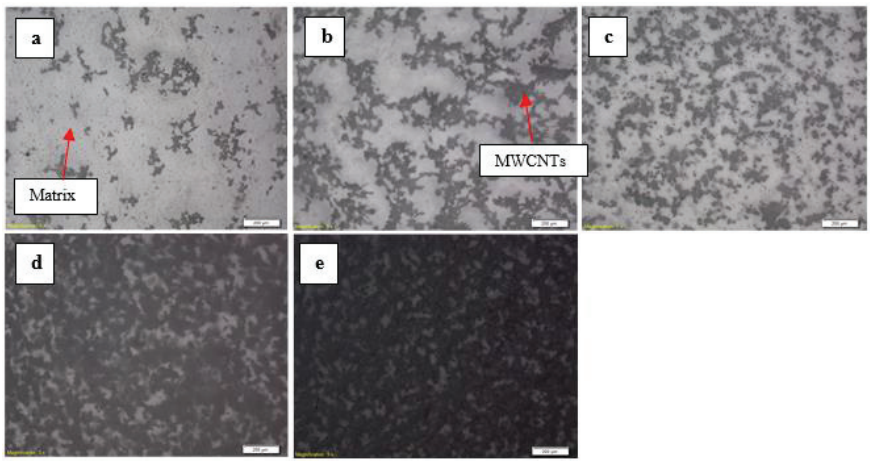

Fig. 3. Microscope images of MWCNTs/cyanoacrylate nanocomposite under total magnification of 300X at different volume percentages of (a) 0.1 vol%; (b) 0.2 vol%; (c) 0.3 vol%; (d) 0.4 vol%; (e) 0.5 vol%.

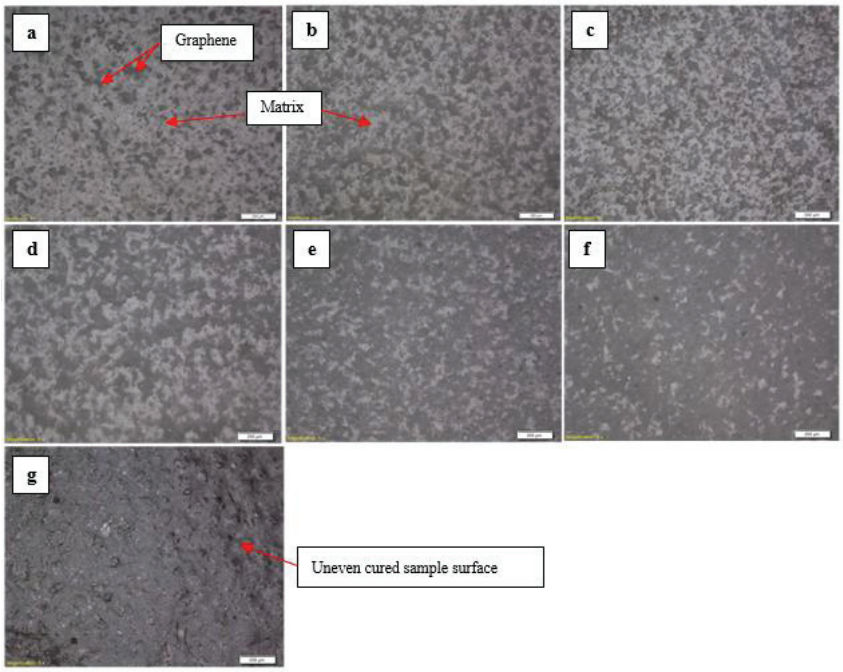

Fig. 4. Microscope images of graphene /cyanoacrylate nanocomposite under total magnification of 300X at different volume percentages of (a) 0.1 vol%; (b) 0.2 vol%; (c) 0.3 vol%; (d) 0.4 vol%; (e) 0.5 vol%; (f) 1 vol%; (g) 2 vol%.

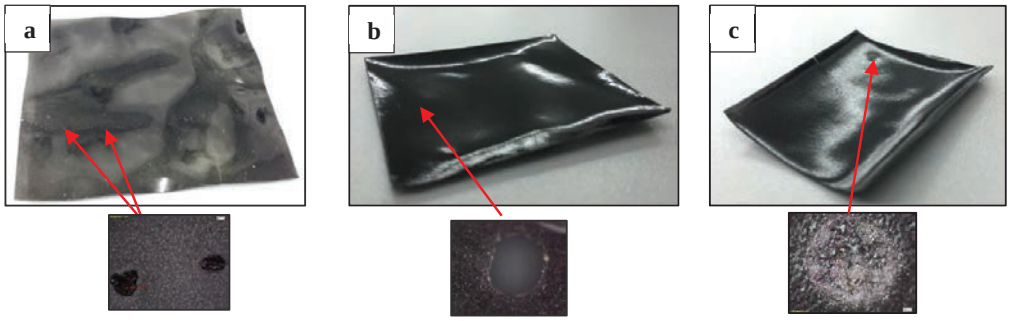

Fig. 5. Images of cyanoacrylate nanocomposite (a) 0.5 vol% MWCNTs; (b) 1 vol% graphene; (c) 2 vol% graphene

3.3. Thermal conductivity analysis

Thermal conductivity analysis were performed at room temperature to investigate the effect of different volume percentage of nanofillers on the thermal conductivity of the as-synthesized nanocomposites. Fig. 6. shows the thermal conductivity values of cured samples at different vol% of graphene and MWCNTs. The thermal conductivity for pure cyanoacrylate is 0.11 W/mK at room temperature. It can be seen that the thermal conductivity

of both MWCNTs/cyanoacrylate and graphene/cyanoacrylate increased with the increasing volume percentage from 0.1-0.4 vol% and 0.1-0.5 vol%, respectively. The increased of thermal conductivity can be related to the increasing

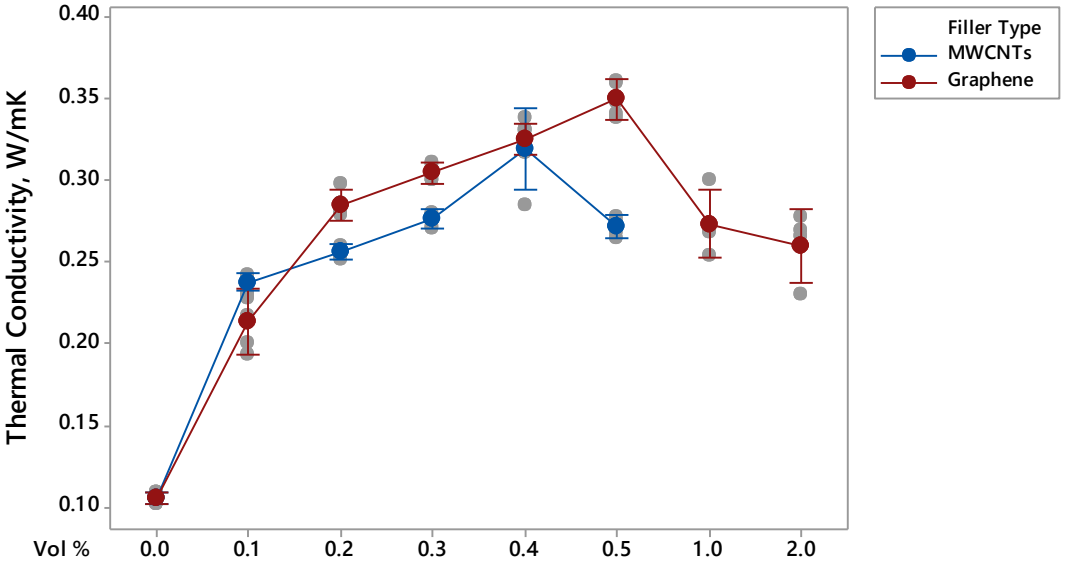

Fig. 6. Thermal conductivity of graphene and MWCNTs nanofillers cyanoacrylate composite at different loading.

amount of the heat dissipation pathway which have high thermal conductivity. During the pre-cured stage, graphene showed better dispersion compared to MWCNTs in cyanoacrylate without increasing the viscosity of mixture. Thus, nanocomposites with flat surface and no trapped bubbles can be easily synthesized. However, MWCNTs demonstrated good dispersion at volume percentage less than 0.4 vol%. This is because the viscosity of MWCNTs gradually increased when more amount was added into acetone which is in agreement with the observation by Martin-Gallego et al.[6]. Therefore, the maximum thermal conductivity values were 0.32 W/mK and 0.35 W/mK for MWCNTs/cyanoacrylate and graphene/ cyanoacrylate, respectively. These values have been increased as high as 204 % and 233% as compared to the thermal conductivity of pure cyanoacrylate. However, the increase of nanofilers at 0.5 vol% (MWCNTs) and 1.0 vol% (graphene) resulted in decreasing the thermal conductivity. The factors of decreasing thermal conductivity at high loading of nanofillers can be attributed to the poor dispersion resulting from the agglomeration which is caused by bubble and curved surface formation on the samples. The trapped bubbles became an insulator to the thermal conductivity path. Therefore, a small amount of MWCNTs and graphene is enough and they can significantly enhance thermal conductivity of cyanoacrylate[7].

4. Conclusions

In summary, we have successfully produced two series of nanocomposites: MWCNTs/cyanoacrylate and graphene/cyanoacrylate. Microscope observation revealed the uniformly dispersed MWCNTs and graphene, respectively on the cyanoacrylate matrix. The increase of nanofillers volume percentage increased the thermal conductivity values at a maximum of 0.32 W/mK and 0.35 W/mK for MWCNTs/cyanoacrylate and graphene/cyanoacrylate, respectively. With further increased of volume percentage, the thermal conductivity values were found to decrease due to the formation of bubbles and curved surface which inhibit the thermal flow between nanofillers and cyanoacrylate matrix. This work opens up new possibilities for the improvement of current TIP thermal conductivity for the fabrication of magnetic recording heads utilized for hard drive manufacturing.

Acknowledgements

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